US009319633B1

(12) **United States Patent**
Birkenes et al.

(10) **Patent No.: US 9,319,633 B1**
(45) **Date of Patent: Apr. 19, 2016**

(54) **ULTRASONIC ECHO CANCELER-BASED TECHNIQUE TO DETECT PARTICIPANT PRESENCE AT A VIDEO CONFERENCE ENDPOINT**

(71) Applicant: **Cisco Technology, Inc.**, San Jose, CA (US)

(72) Inventors: **Oystein Birkenes**, Oslo (NO); **Lennart Burenius**, Oslo (NO); **Kristian Tangeland**, Oslo (NO)

(73) Assignee: **Cisco Technology, Inc.**, San Jose, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/662,691**

(22) Filed: **Mar. 19, 2015**

(51) **Int. Cl.**

H04N 7/14	(2006.01)
H04N 7/15	(2006.01)
H04L 29/06	(2006.01)
G10L 17/22	(2013.01)
G10L 25/21	(2013.01)

(52) **U.S. Cl.**
CPC ***H04N 7/15*** (2013.01); ***G10L 17/22*** (2013.01); ***G10L 25/21*** (2013.01); ***H04L 65/1059*** (2013.01); ***H04L 65/403*** (2013.01)

(58) **Field of Classification Search**
CPC H04N 7/14
USPC 348/14.01, 14.08, 14.05, 14.12
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,374,145 B1 4/2002 Lignoul
8,811,119 B2 8/2014 Aarts et al.
2009/0046538 A1* 2/2009 Breed B60C 11/24 367/93
2012/0001875 A1 1/2012 Li et al.
2013/0129102 A1 5/2013 Li et al.
2014/0368604 A1* 12/2014 Lalonde H04N 7/147 348/14.08

OTHER PUBLICATIONS

Tarzia, "Acoustic Sensing of Location and User Presence on Mobile Computers", Technical Report NWU-EECS-11-09, Northwestern University—Electrical Engineering and Computer Science Department, Aug. 31, 2011, 113 pages.
Ricci et al., "Experimental validation of an ultrasound-based measurement system for human motion detection and analysis", Instrumentation and Measurement Technology Conference (I2MTC), 2013 IEEE International , vol., no., pp. 300,305, May 6-9, 2013.
Bloom et al, "Digital Ultrasonic Motion Detector", Teaching Projects in SIPL, http://sipl.technion.ac.il/Info/Teaching_Projects_5-2-09_e.shtml, Sep. 2011, 5 pages.

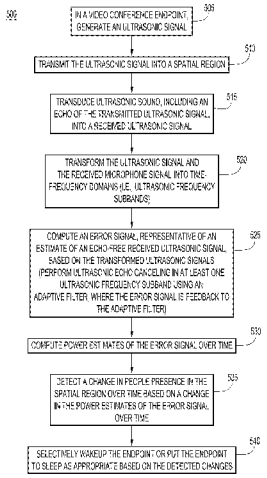
* cited by examiner

Primary Examiner — Olisa Anwah
(74) *Attorney, Agent, or Firm* — Edell, Shapiro & Finnan, LLC

(57) **ABSTRACT**

A loudspeaker transmits an ultrasonic signal into a spatial region. A microphone transduces ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region into a received ultrasonic signal. A controller transforms the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains that cover respective ultrasound frequency ranges. The controller computes an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasonic signal and the transformed received ultrasonic signal. The controller computes power estimates of the error signal over time, and detects a change in people presence in the spatial region based on a change in the power estimates of the error signal over time.

20 Claims, 6 Drawing Sheets



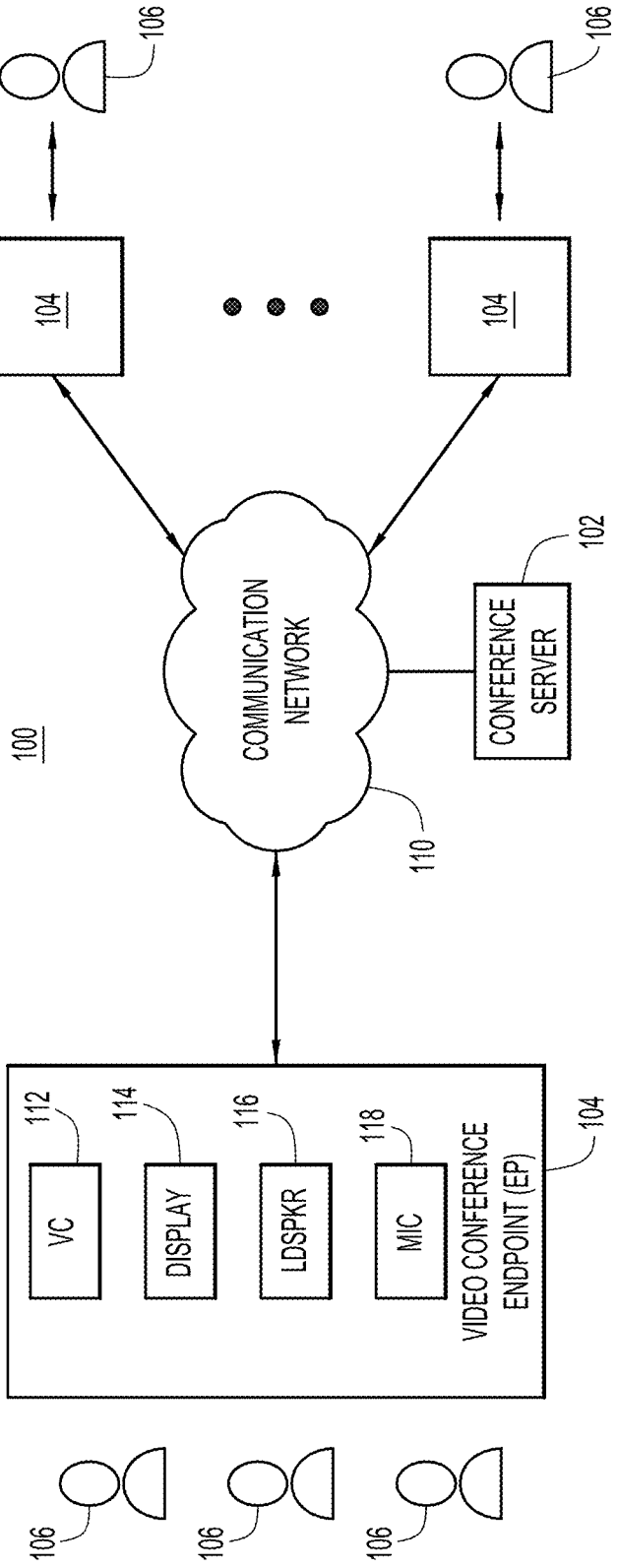

106
106
104
104
COMMUNICATION NETWORK
CONFERENCE SERVER
102
100
110
112
114
116
118
VC
DISPLAY
LDSPKR
MIC
VIDEO CONFERENCE ENDPOINT (EP)
104
106
106
106

FIG.1

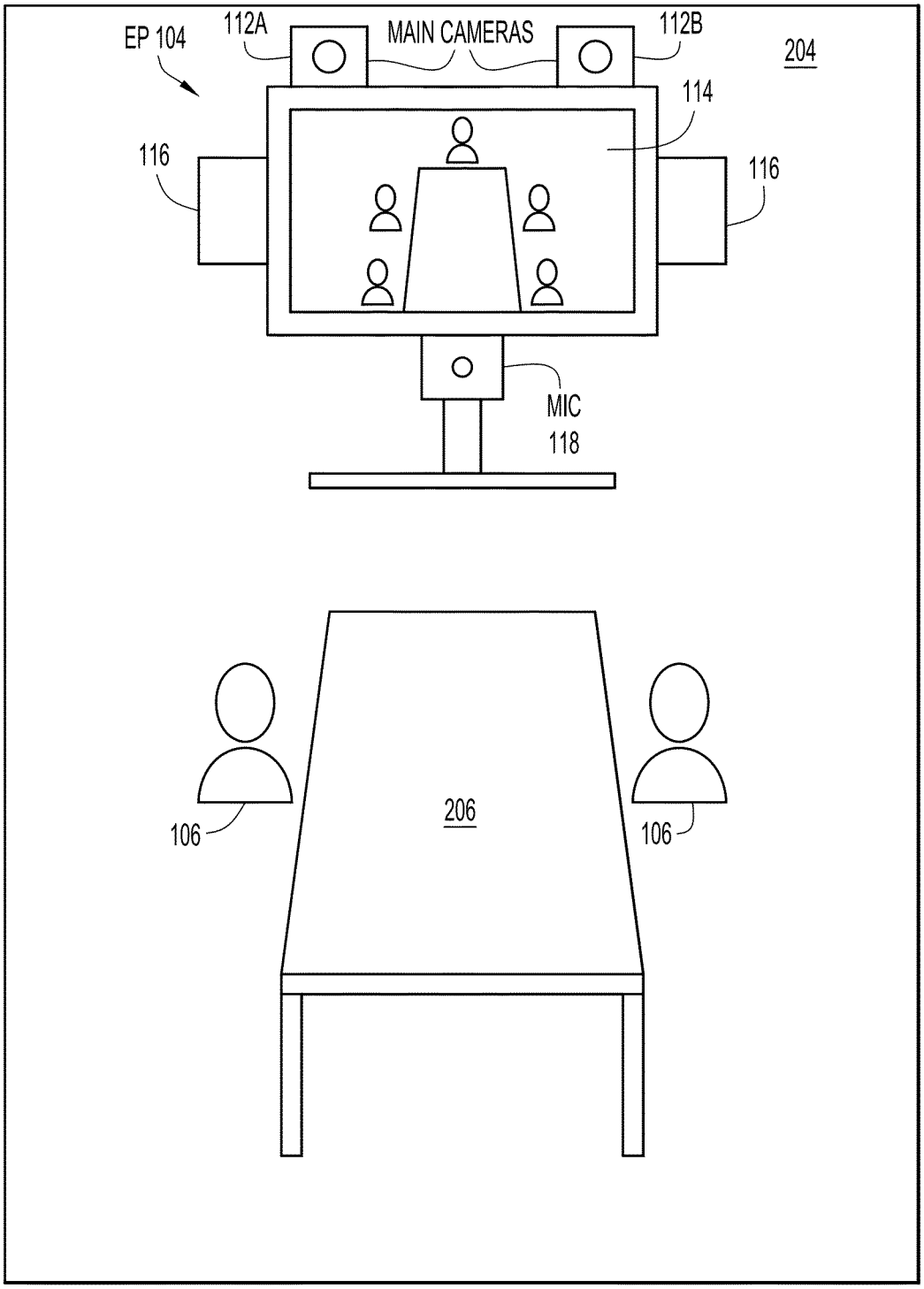

EP 104
112A
MAIN CAMERAS
112B
204
114
116
116
MIC
118
206
106
106

FIG.2

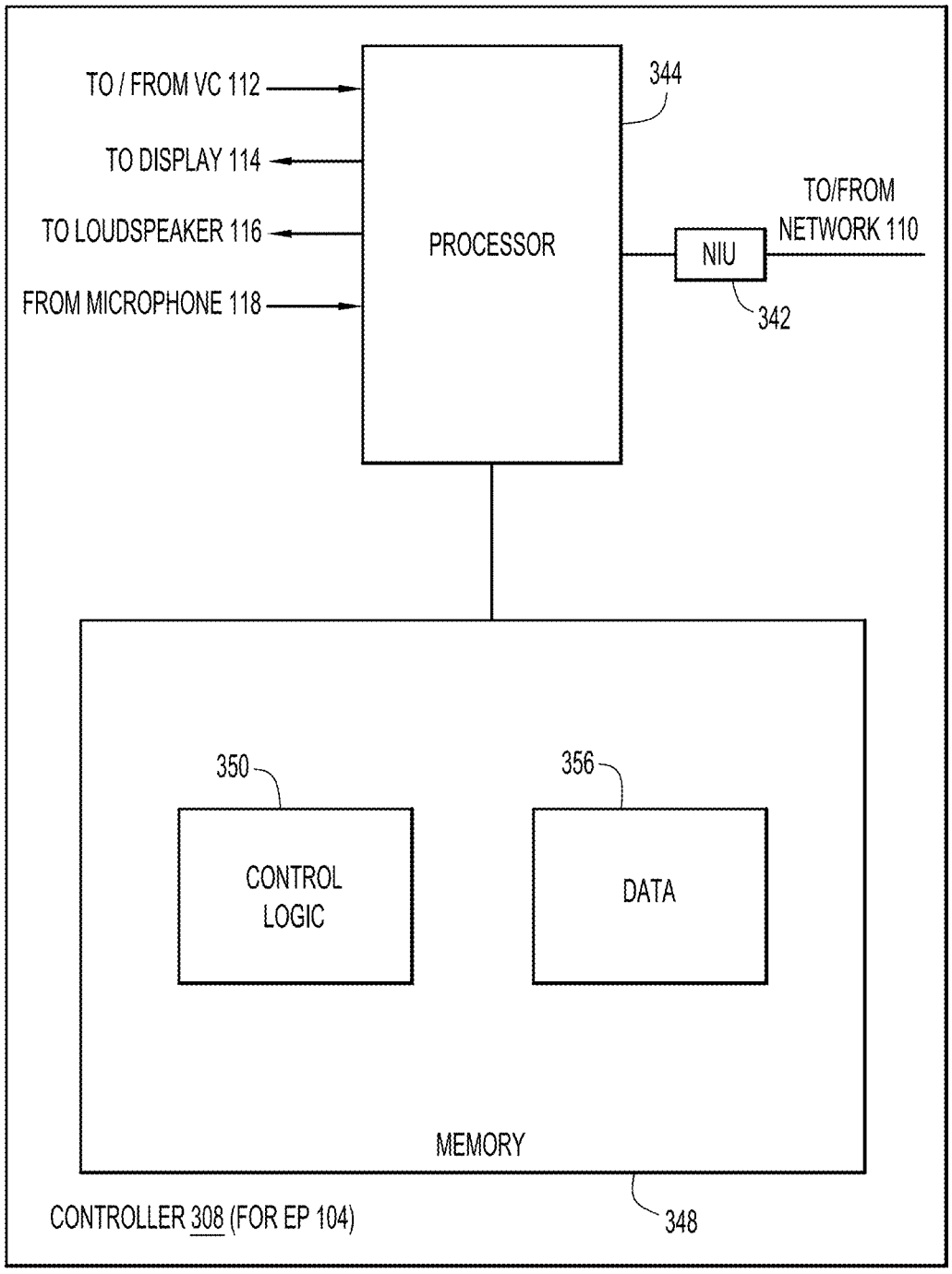

TO / FROM VC 112
TO DISPLAY 114
TO LOUDSPEAKER 116
FROM MICROPHONE 118
PROCESSOR
344
NIU
342
TO/FROM NETWORK 110
350
CONTROL LOGIC
356
DATA
MEMORY
348
CONTROLLER 308 (FOR EP 104)

FIG.3

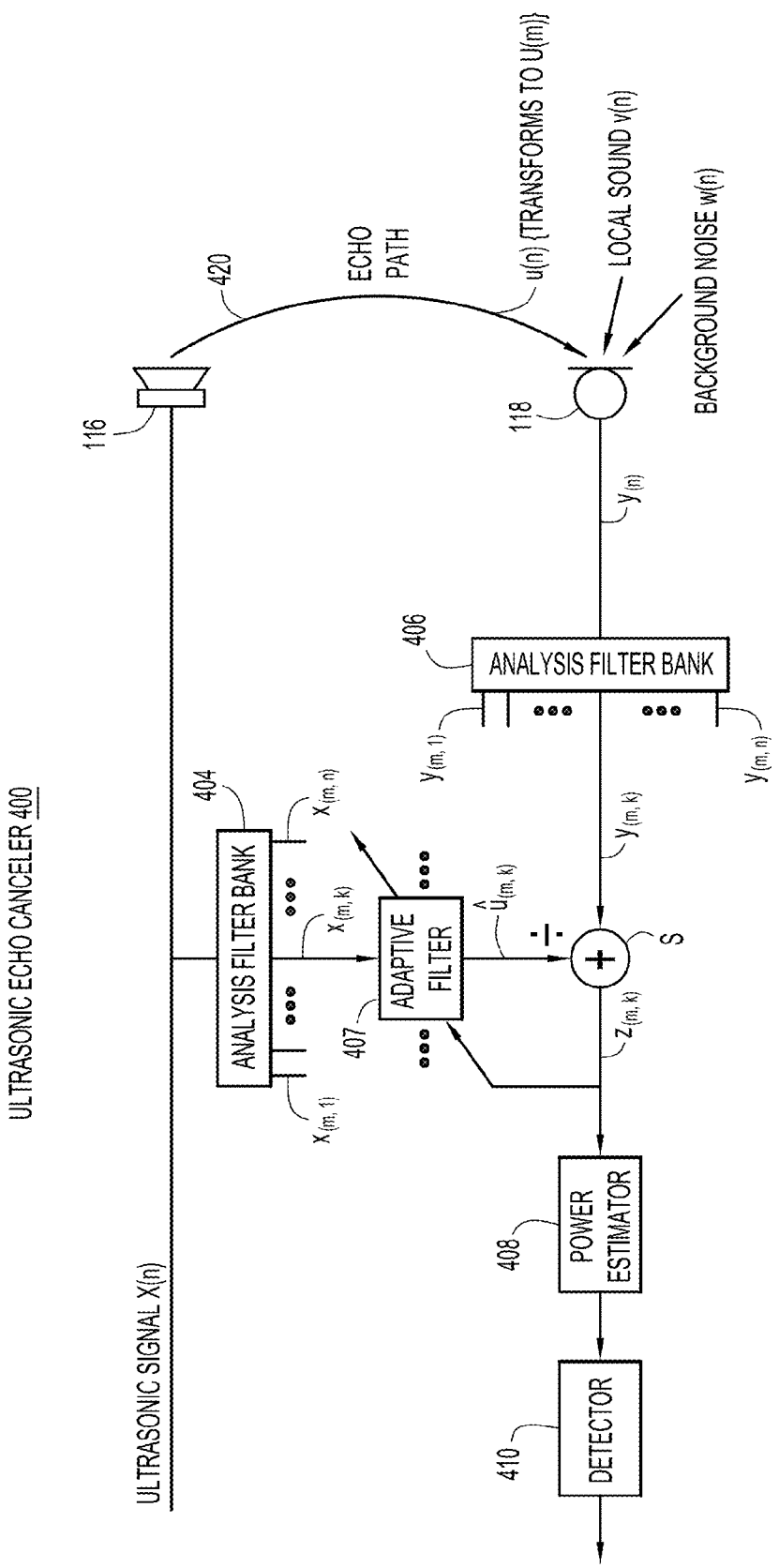

ULTRASONIC ECHO CANCELER 400
ULTRASONIC SIGNAL X(n)
116
420
ECHO PATH
u(n) {TRANSFORMS TO U(m)}
LOCAL SOUND v(n)
BACKGROUND NOISE w(n)
118
y(n)
406
ANALYSIS FILTER BANK
y(m, 1)
y(m, n)
y(m, k)
404
ANALYSIS FILTER BANK
x(m, n)
x(m, k)
x(m, 1)
ADAPTIVE FILTER
407
û(m, k)
-
+
S
z(m, k)
408
POWER ESTIMATOR
410
DETECTOR

FIG.4

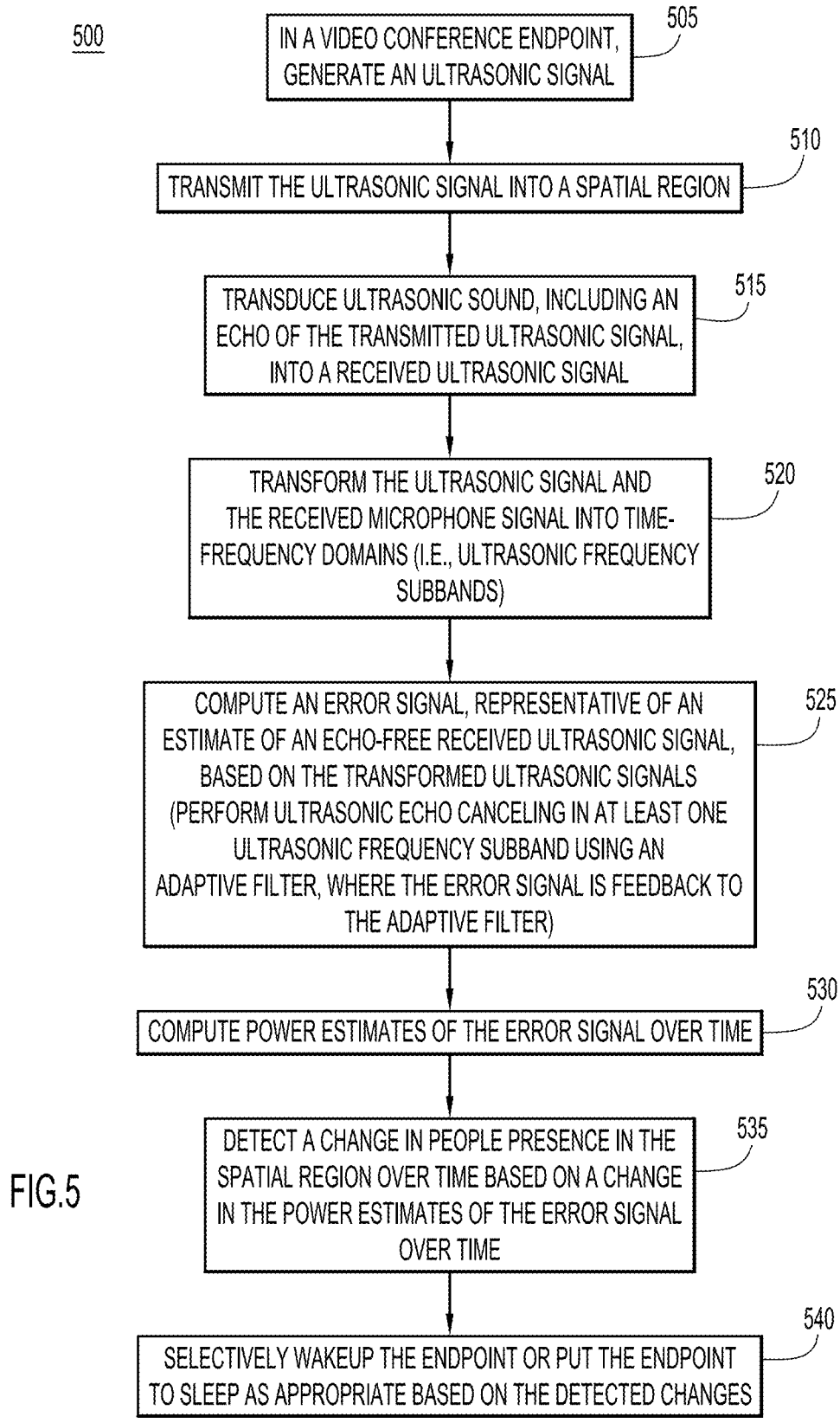

500
IN A VIDEO CONFERENCE ENDPOINT, GENERATE AN ULTRASONIC SIGNAL
505
TRANSMIT THE ULTRASONIC SIGNAL INTO A SPATIAL REGION
510
TRANSDUCE ULTRASONIC SOUND, INCLUDING AN ECHO OF THE TRANSMITTED ULTRASONIC SIGNAL, INTO A RECEIVED ULTRASONIC SIGNAL
515
TRANSFORM THE ULTRASONIC SIGNAL AND THE RECEIVED MICROPHONE SIGNAL INTO TIME-FREQUENCY DOMAINS (I.E., ULTRASONIC FREQUENCY SUBBANDS)
520
COMPUTE AN ERROR SIGNAL, REPRESENTATIVE OF AN ESTIMATE OF AN ECHO-FREE RECEIVED ULTRASONIC SIGNAL, BASED ON THE TRANSFORMED ULTRASONIC SIGNALS (PERFORM ULTRASONIC ECHO CANCELING IN AT LEAST ONE ULTRASONIC FREQUENCY SUBBAND USING AN ADAPTIVE FILTER, WHERE THE ERROR SIGNAL IS FEEDBACK TO THE ADAPTIVE FILTER)
525
COMPUTE POWER ESTIMATES OF THE ERROR SIGNAL OVER TIME
530
DETECT A CHANGE IN PEOPLE PRESENCE IN THE SPATIAL REGION OVER TIME BASED ON A CHANGE IN THE POWER ESTIMATES OF THE ERROR SIGNAL OVER TIME
535
SELECTIVELY WAKEUP THE ENDPOINT OR PUT THE ENDPOINT TO SLEEP AS APPROPRIATE BASED ON THE DETECTED CHANGES
540

FIG.5

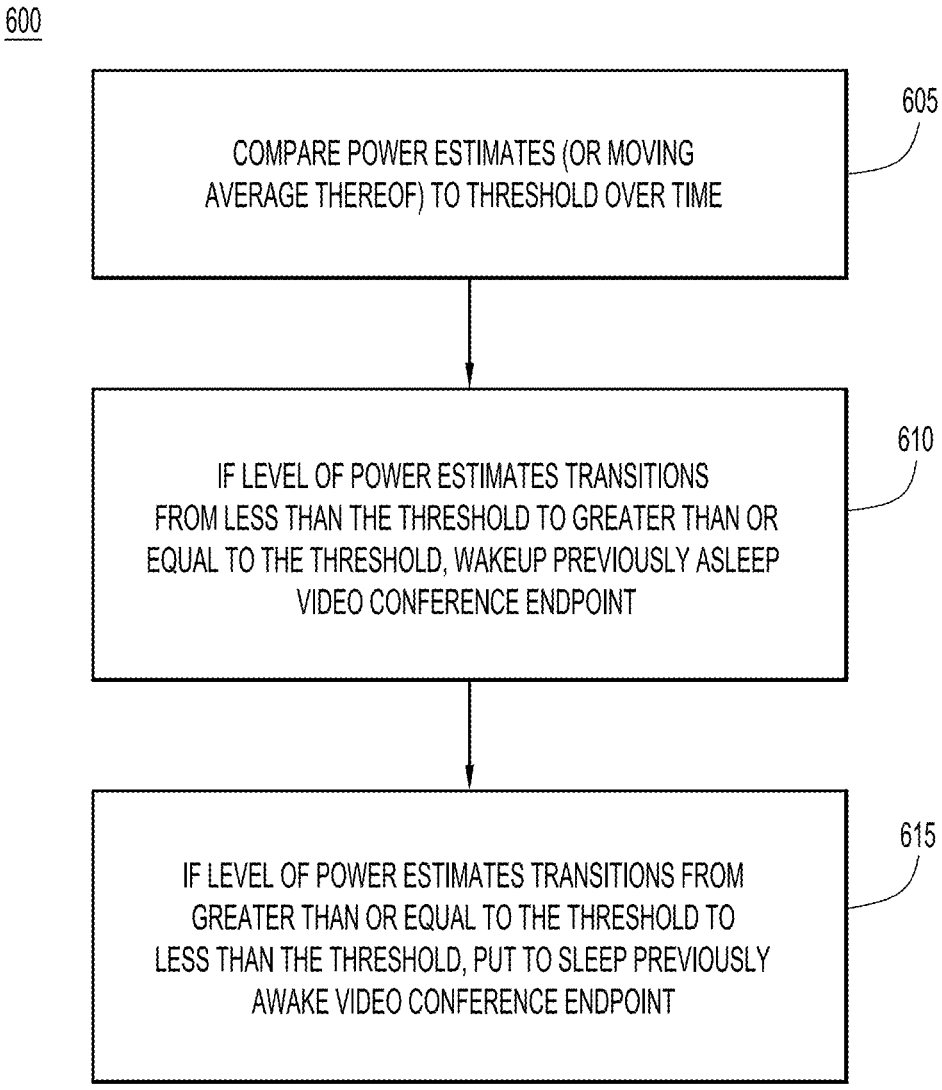

600
COMPARE POWER ESTIMATES (OR MOVING AVERAGE THEREOF) TO THRESHOLD OVER TIME
605
IF LEVEL OF POWER ESTIMATES TRANSITIONS FROM LESS THAN THE THRESHOLD TO GREATER THAN OR EQUAL TO THE THRESHOLD, WAKEUP PREVIOUSLY ASLEEP VIDEO CONFERENCE ENDPOINT
610
IF LEVEL OF POWER ESTIMATES TRANSITIONS FROM GREATER THAN OR EQUAL TO THE THRESHOLD TO LESS THAN THE THRESHOLD, PUT TO SLEEP PREVIOUSLY AWAKE VIDEO CONFERENCE ENDPOINT
615

FIG.6

ULTRASONIC ECHO CANCELER-BASED TECHNIQUE TO DETECT PARTICIPANT PRESENCE AT A VIDEO CONFERENCE ENDPOINT

TECHNICAL FIELD

The present disclosure relates to detecting the presence of people using ultrasonic sound.

BACKGROUND

A video conference endpoint includes a camera and a microphone to capture video and audio of a participant in a meeting room, and a display to present video. While no participant is in the meeting room, the endpoint may be placed in a standby or sleep mode to conserve power. In standby, components of the endpoint, such as the camera and display, may be deactivated or turned-off. When a participant initially enters the meeting room, the endpoint remains in standby until the participant manually wakes-up the endpoint using a remote control or other touch device. If the participant is unfamiliar with the endpoint or if the touch device is not readily available, the simple act of manually activating the endpoint may frustrate the participant and diminish his or her experience.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a video conference (e.g., teleconference) environment in which embodiments to automatically detect the presence of people proximate a video conference endpoint in a room and selectively wakeup the video conference endpoint or put the endpoint to sleep may be implemented, according to an example embodiment.

FIG. **2** is an illustration of a video conference endpoint deployed in a room, according to an example embodiment.

FIG. **3** is a block diagram of a controller of the video conference endpoint, according to an example embodiment.

FIG. **4** is a block diagram of an ultrasonic echo canceler implemented in the video conference endpoint to detect whether people are present in a room, according to an example embodiment.

FIG. **5** is a flowchart of a method of detecting whether people are present in a room using the ultrasonic echo canceler of the video conference endpoint, and using the detections to selectively wakeup the endpoint or put the endpoint to sleep, according to an example embodiment.

FIG. **6** is a series of operations expanding on detection and wakeup/sleep control operations from the method of FIG. **5**, according to an example embodiment.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

In accordance with one embodiment, a loudspeaker transmits an ultrasonic signal into a spatial region. A microphone transduces ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region into a received ultrasonic signal. A controller transforms the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains that cover respective ultrasound frequency ranges. The controller computes an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasonic signal and the transformed received ultrasonic signal. The controller computes power estimates of the error signal over time, and detects a change in people presence in the spatial region over time based on the power estimates of the error signal over time.

Example Embodiments

With reference to FIG. **1**, there is depicted a block diagram of an example video conference (e.g., teleconference) environment **100** in which embodiments to automatically detect the presence of people (i.e., "people presence") proximate a video conference endpoint (EP) and selectively wakeup the endpoint or put the endpoint to sleep may be implemented. Video conference environment **100** includes video conference endpoints **104** operated by local users/participants **106** (also referred to as "people" **106**) and configured to establish audio-visual teleconference collaboration sessions with each other over a communication network **110**. Communication network **110** may include one or more wide area networks (WANs), such as the Internet, and one or more local area networks (LANs). A conference server **102** may also be deployed to coordinate the routing of audio-video streams among the video conference endpoints.

Each video conference endpoint **104** may include multiple video cameras (VC) **112**, a video display **114**, a loudspeaker (LDSPKR) **116**, and one or more microphones (MIC) **118**. Endpoints **104** may be wired or wireless communication devices equipped with the aforementioned components, such as, but not limited to laptop and tablet computers, smartphones, etc. In a transmit direction, endpoints **104** capture audio/video from their local participants **106** with microphone **118**/VC **112**, encode the captured audio/video into data packets, and transmit the data packets to other endpoints or to the conference server **102**. In a receive direction, endpoints **104** decode audio/video from data packets received from the conference server **102** or other endpoints and present the audio/video to their local participants **106** via loudspeaker **116**/display **114**.

Referring now to FIG. **2**, there is depicted an illustration of video conference endpoint **104** deployed in a conference room **204** (depicted simplistically as an outline in FIG. **2**), according to an embodiment. Video conference endpoint **104** includes video cameras **112**A and **112**B positioned proximate and centered on display **114**. Cameras **112**A and **112**B (collectively referred to as "cameras **112**") are each operated under control of endpoint **104** to capture video of participants **106** seated around a table **206** opposite from or facing (i.e., in front of) the cameras (and display **114**). The combination of two center video cameras depicted in FIG. **2** is only one example of many possible camera combinations that may be used, including video cameras spaced-apart from display **114**, as would be appreciated by one of ordinary skill in the relevant arts having read the present description. As depicted in the example of FIG. **2**, microphone **118** is positioned adjacent to, and centered along, a bottom side of display **114** (i.e., below the display) so as to receive audio from participants **106** in room **204**, although other positions for the microphone are possible.

According to embodiments presented herein, video conference endpoint **104** includes an ultrasonic echo canceler to detect whether participants are present (i.e., to detect "people presence") in room **204**. Also, endpoint **104** may use people presence detection decisions from the ultrasonic echo canceler to transition the endpoint from sleep to awake or vice versa, as appropriate. The ultrasonic echo canceler is described below in connection with FIG. **4**.

Reference is now made to FIG. **3**, which shows an example block diagram of a controller **308** of video conference endpoint **104** configured to perform techniques described herein. There are numerous possible configurations for controller **308** and FIG. **3** is meant to be an example. Controller **308** includes a network interface unit **342**, a processor **344**, and memory **348**. The network interface (I/F) unit (NIU) **342** is, for example, an Ethernet card or other interface device that allows the controller **308** to communicate over communication network **110**. Network I/F unit **342** may include wired and/or wireless connection capability.

Processor **344** may include a collection of microcontrollers and/or microprocessors, for example, each configured to execute respective software instructions stored in the memory **348**. The collection of microcontrollers may include, for example: a video controller to receive, send, and process video signals related to display **112** and video cameras **112**; an audio processor to receive, send, and process audio signals (in human audible and ultrasonic frequency ranges) related to loudspeaker **116** and microphone array **118**; and a high-level controller to provide overall control. Portions of memory **348** (and the instructions therein) may be integrated with processor **344**. As used herein, the terms "audio" and "sound" are synonymous and interchangeable.

Processor **344** may send pan, tilt, and zoom commands to video cameras **112** to control the cameras. Processor **344** may also send wakeup (i.e., activate) and sleep (i.e., deactivate) commands to video cameras **112**. The camera wakeup command is used to wakeup cameras **112** to a fully powered-on operational state so they can capture video, while the camera sleep command is used to put the cameras to sleep to save power. In the sleep state, portions of cameras **112** are powered-off or deactivated and the cameras are unable to capture video. Processor **344** may similarly send wakeup and sleep commands to display **114** to wakeup the display or put the display to sleep. In another embodiment, processor **344** may selectively wakeup and put to sleep portions of controller **308** while the processor remains active. When any of cameras **112**, display **114**, and portions of controller **308** are asleep, endpoint **104** is said to be in standby or asleep (i.e., in the sleep mode). Conversely, when all of the components of endpoint **104** are awake and fully operational, endpoint **104** is said to be awake. Operation of the aforementioned components of endpoint **104** in sleep and awake modes, and sleep and wakeup commands that processor **344** may issue to transition the components between the sleep and awake modes are known to those of ordinary skill in the relevant arts.

The memory **348** may comprise read only memory (ROM), random access memory (RAM), magnetic disk storage media devices, optical storage media devices, flash memory devices, electrical, optical, or other physical/tangible (e.g., non-transitory) memory storage devices. Thus, in general, the memory **348** may comprise one or more computer readable storage media (e.g., a memory device) encoded with software comprising computer executable instructions and when the software is executed (by the processor **344**) it is operable to perform the operations described herein. For example, the memory **348** stores or is encoded with instructions for control logic **350** to perform operations described herein to (i) implement an ultrasonic echo canceler to detect a change in people presence, and (ii) wakeup endpoint **104** or put the endpoint to sleep based on the detected people presence.

In addition, memory **348** stores data/information **356** used and generated by logic **350**, including, but not limited to, adaptive filter coefficients, power estimate thresholds indicative of people presence, predetermined timeouts, and current operating modes of the various components of endpoint **104** (e.g., sleep and awake states), as described below.

With reference to FIG. **4**, there is depicted a block diagram of example ultrasonic echo canceler **400** implemented in endpoint **104** to detect people presence. Ultrasonic echo canceler **400** includes loudspeaker **116**, microphone **118**, analysis filter banks **404** and **406**, a differencer S (i.e. a subtractor S), an adaptive filter **407** associated with adaptive filter coefficients, a power estimator **408**, and a people presence detector **410**. Analysis filter banks **404** and **406**, differencer S, adaptive filter **407**, power estimator **408**, and detector **410** represent ultrasonic sound signal processing modules that may be implemented in controller **308**. As will be described in detail below, ultrasonic echo canceler **400** detects people presence in room **204** (i.e. when people are and are not present in the room), and controller **308** uses the people presence indications to selectively wakeup endpoint **104** when people are present (e.g., have entered the room) or put the endpoint to sleep when people are not present (e.g., have left the room), as indicated by the echo canceler. Echo canceler **104** and controller **308** perform the aforementioned operations automatically, i.e., without manual intervention. Also, echo canceler **104** and controller **308** are operational to perform the operations described herein while endpoint **104** (or components thereof) is both awake and asleep.

Ultrasonic echo canceler **400** operates as follows. Controller **308** generates an ultrasonic signal x(n), where n is a time index that increases with time, and provides the ultrasonic signal x(n) to an input of loudspeaker **116**. Loudspeaker **116** transmits ultrasonic signal x(n) into a spatial region (e.g., room **204**). Ultrasonic signal x(n) has a frequency in an audio frequency range that is generally beyond the frequency range of human hearing, but which can be transmitted from most loudspeakers and picked up by most microphones. This frequency range is generally accepted as approximately 20 Khz and above, however, embodiments described herein may also operate at frequencies below 20 Khz (e.g., 19 Khz) that most people would not be able to hear. The transmitted ultrasonic signal bounces around in room **204** before it is received and thereby picked up by microphone **118** via an echo path **420**. Microphone **118** transduces sound received at the microphone into a microphone signal y(n), comprising ultrasonic echo u(n), local sound v(n), and background noise w(n). Microphone **118** provides microphone signal y(n) to analysis filter bank **406**, which transforms the microphone signal y(n) into a time-frequency domain including multiple ultrasonic frequency subbands Y(m,1)-Y(m,N) spanning an ultrasonic frequency range. Also, analysis filter bank **404** transforms ultrasonic signal x(n) into a time-frequency domain including multiple ultrasonic frequency subbands X(m,1)-X(m,N) spanning an ultrasonic frequency range.

In a k'th one of the ultrasonic frequency subbands X(m,k), adaptive filter **407** generates an estimate $\hat{U}(m, k)$ of the subband echo signal U(m,k), where m denotes the time frame index. Differencer S subtracts the echo estimate $\hat{U}(m, k)$ from the subband microphone signal Y(m,k) output by analysis filter bank **406** to form an error (signal) Z(m,k) that is fed back into adaptive filter **407**. Adaptive filter coefficients of adaptive filter **407** are adjusted responsive to the fed back error signal. Power estimator **408** computes a running estimate of the mean squared error (power) $E|Z(m, k)|^2$ of the error signal Z(m,k) and detector **410** detects a changing people presence, e.g., when somebody walks into room **204** where nobody has been for a while, based on the mean squared power.

The following is an explanation of how the mean squared error $E|Z(m, k)|^2$ is a good indicator of whether someone enters the room **204**. Let $X_k(m)=[X(m,k), X(m-1,k) \ldots$

$X(m-M+1, k)]^T$ denote a delay line for adaptive filter **407**, where M denotes the number of adaptive filter coefficients employed in the adaptive filter. Furthermore, let $\hat{H}_k(m)$ denote the vector of the M adaptive filter coefficients. The echo estimate can then be written:

$$\hat{U}(m,k)=X_k^H(m)\hat{H}_k(m) \quad (1)$$

where $(\cdot)^H$ denotes the Hermitian operator. The time-frequency domain transformation of the microphone signal y(n) is given by:

$$Y(m,k)=X_k^H(m)H_k(m)+V(m,k)+W(m,k) \quad (2)$$

where $H_k(m)$ is the unknown optimal linear filter, and where it is assumed that the error introduced by analysis filter bank **406** is negligible. The error is then given by the following equation (3):

$$Z(m,k)=Y(m,k)-\hat{U}(m,k)=X_k^H(m)(H_k(m)-\hat{H}_k(m))+V(m,k)+W(m,k)$$

and the mean squared error can be written as the following equation (4):

$$E|Z(m,k)|^2$$

$$=(H_k^H(m)-\hat{H}_k^H(m))R_{X_k}(m)(H_k(m)-\hat{H}_k(m))+\sigma_V^2(m,k)$$

$$+\sigma_W^2(m,k)$$

where $R_{X_k}(m)=(EX_k(m)X_k^H(m))$ is the correlation matrix, $\sigma_V^2(m,k)=E|V(m,k)|^2$ and $\sigma_W^2(m,k)=E|W(m,k)|^2$. Assuming x(n) is stationary, the correlation matrix will be constant and independent of m, i.e., $R_{X_k}(m)=R_{X_k}$. Then the following relationship applies:

$$E|Z(m,k)|^2=\left\|H_k(m)-\hat{H}_k(m)\right\|_{R_{X_k}}^2+\sigma_V^2(m,k)+\sigma_W^2(m,k) \quad (5)$$

where $\|\cdot\|_A^2$ denotes the A-norm. From equation (5) it is seen that $E|Z(m,k)|^2$ comprises three main terms. The first term is the R_{X_k}-norm of the divergence between optimal and estimated filter coefficients, the second term is the power of the local sound signal (v(n)), and the third terms is the power of the background noise (w(n)). It is assumed in the following that the power of the background noise is stationary and time-invariant.

When nobody is in room **204**, and nobody has been in the room for a while, the acoustic room impulse response will be approximately static (no change) and adaptive filter **407** will be in a well converged state and provide a good estimate $\hat{U}(m,k)$ of subband echo signal U(m,k). Therefore we have that

$$\left\|H_k(m)-\hat{H}_k(m)\right\|_{R_{X_k}}^2$$

is approximately equal to 0. Moreover, there are no or minimal local sounds coming from within room **204** (i.e., $\sigma_V^2(m,k)=0$) except from the ultrasonic background noise $\sigma_W^2(m,k)$. Thus the mean squared error $E|Z(m,k)|^2$ will be small comprising small residual echo and background noise.

When somebody enters room **204**, the acoustic room impulse response will change abruptly and adaptive filter **407** will no longer be in a converged state, and it will therefore provide a poor estimate $\hat{U}(m,k)$ of subband echo signal U(m,k). Also, as long as there is movement in the room, adaptive filter **407** attempts to track the continuously changing impulse response and may never achieve the same depth of convergence. Furthermore, movement in the room may cause Doppler shift, so that some of the energy in one frequency subband leaks over to a neighboring subband. The Doppler Effect can result in both a changed impulse response for a subband and also a mismatch between audio content in the loudspeaker subband output from analysis filter bank **404** and the microphone subband output from analysis filter bank **406**. Both of these effects lead to residual echo and thus

$$\left\|H_k(m)-\hat{H}_k(m)\right\|_{R_{X_k}}^2 \gg 0.$$

Moreover, if the person entering the room makes some sound in the ultrasonic frequency range, the power $\sigma_V^2(m,k)>0$ of this sound will also contribute to a large error signal. The mean squared error (power) is a theoretical variable that is useful in theoretical analysis. In practice, power estimator **408** estimates the power of error signal Z(m,k). To do this, either a rectangular window of length L may be used as in:

$$P_Z(m,k)=\frac{1}{L}\sum_{l=0}^{L-1}|Z(m-l,k)|^2 \quad (6)$$

or an exponential recursive weighting may be used as in:

$$P_Z(m,k)=\alpha P_Z(m-1,k)+(1-\alpha)|Z(m,k)|^2 \quad (7)$$

where α is a forgetting factor in the range [0,1].

As mentioned above, detector **410** receives the power estimates of the error signal and performs people presence detection based on the power estimates. As indicated above, as soon as a person enters room **204**, the power estimate of the error signal will change from a relatively small level to relatively large level. Thus, detection may be performed by comparing the power estimate of the error signal over time with a threshold that may be set, for example, to a few dBs above the steady-state power (e.g., the steady-state power is the power corresponding to when adaptive filter **407** is in a converged state, such that the threshold is indicative of the steady-state or converged state of the adaptive filter), or, if a running estimate of the variance of the power signal is also computed, to a fixed number of standard deviations above the steady-state power. Another embodiment estimates a statistical model of the power signal, and bases the decision on likelihood evaluations. It is desirable to design adaptive filter **407** for deep convergence instead of fast convergence. This is a well known tradeoff that can be controlled in stochastic gradient descent algorithms like normalized least mean squares (NLMS) with a step size and/or a regularization parameter.

With a single adaptive filter in one narrow ultrasonic frequency subband, e.g., k, as depicted in FIG. **4**, the detection performance may be degraded due to a notch in the frequency response of loudspeaker **116**, a notch in the frequency response of microphone **118**, or an absorbent in room **204** within that particular frequency subband. Therefore, a more robust method may be achieved using an individual adaptive filter in each of multiple frequency subbands X(m,1)-X(m,N) (i.e., replicate adaptive filter **407**) for each frequency subband, to produce an estimate of echo for each frequency subband. In that case, an error signal is generated corresponding to each of the frequency subbands from analysis filter bank **404**, and an error signal for each frequency subband is produced based on the estimate of the echo for that frequency subband and a corresponding one of the transformed micro-

phone signal frequency subbands Y(m,k) from analysis filter bank **406**. Power estimator **408** computes a power estimate of the error signal for each of the frequency subbands and then combines them all into a total power estimate across the frequency subbands. For example, the total power estimate across the subbands for a given frame may be computed according to: $P_Z(m)=\alpha P_Z(m-1)+(1-\alpha)\Sigma_k|Z(m, k)|^2$, where Σ_k indicates the sum over all subbands k that are in use. Alternatively, the total power estimate across the subbands may be computed according to: $P_Z(m)=\Sigma_k P_Z(m,k)$. In an embodiment, each power estimate may be a moving average of power estimates so that the total power estimate is a total of the moving average of power estimates.

Ultrasonic signal x(n) may either be an ultrasonic signal that is dedicated to the task of detecting people presence, or an existing ultrasonic signal, such as an ultrasonic pairing signal, as long as endpoint **104** is able to generate and transmit the ultrasonic signal while the endpoint is asleep, i.e., in standby. Best performance may be achieved when ultrasonic signal x(n) is stationary and when there is minimal autocorrelation of the non-zero lags of the subband transmitted loudspeaker signal. The correlation matrix R_{X_k} of ultrasonic signal x(n) may be used to a certain degree to control the relative sensitivity of the people presence detection to the adaptive filter mismatch and the local sound from within the room.

With reference to FIG. **5**, there is a flowchart of an example method **500** of detecting people presence in a spatial region (e.g., room **204**) using ultrasonic echo canceler **400**, and using the detections to selectively wakeup or put to sleep endpoint **104**. Echo canceler **400** and controller **308** are fully operational while endpoint **104** is asleep and awake.

At **505**, processor **308** generates an ultrasonic signal (e.g., x(n)).

At **510**, loudspeaker **116** transmits the ultrasonic signal into a spatial region (e.g., room **204**).

At **510**, microphone **118** transduces sound, including ultrasonic sound that includes an echo of the transmitted ultrasonic signal, into a received ultrasonic signal (e.g., y(n)).

At **515**, analysis filter banks **404** and **406** transform the ultrasonic signal (e.g., u(n)) and the received ultrasonic microphone signal into respective time-frequency domains each having respective ultrasonic frequency subbands.

At **520**, differencer S computes an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasonic signal and the transformed received ultrasonic signal. More specifically, difference **406** subtracts an estimate of the echo signal in the time-frequency domain from the transformed received ultrasonic signal to produce the error signal. This is a closed-loop ultrasonic echo canceling operation performed in at least one ultrasonic frequency subband using adaptive filter **407**, which produces the estimate of the echo signal, where the error signal is fed back to the adaptive filter.

At **525**, power estimator **408** computes power estimates of the error signal over time, e.g., the power estimator repetitively performs the power estimate computation as time progresses to produce a time sequence of power estimates. The power estimates may be a moving average of power estimates based on a current power estimate and one or more previous power estimates.

At **530**, detector **410** detects people presence in the spatial region (e.g., room **204**) over time based on the power estimates of the error signal over time. In an embodiment, detector **410** may detect a change in people presence in the spatial region over time based on a change in the power estimates (or a change in the moving average power estimates) of the error signal over time.

At **535**, processor **344** issues commands to selectively wakeup endpoint **104** or put the endpoint to sleep as appropriate based on the detections at **530**.

In another embodiment, the detection of people presence as described above may activate only those components of endpoint **104**, e.g., video cameras **112**, required by the endpoint to aid in additional processing by processor **344**, such as detecting faces and motion in room **204** based on video captured by the activated/awakened cameras. In other words, the people presence detection triggers face and motion detection by endpoint **104**. If faces and/or motion are detected subsequent to people presence being detected, only then does processor **344** issue commands to fully wakeup endpoint **104**. Thus, the face and motion detection is a confirmation that people have entered room **204**, which may avoid unnecessary wakeups due to false (initial) detections of people presence. Any known or hereafter developed technique to perform face and motion detection may be used in the confirmation operation.

With reference to FIG. **6**, there is a flowchart of operations **600**, which expand on operations **530** and **535** of method **500**.

To detect people presence (or a change in people presence), at **605** detector **410** compares power estimates (or a moving average of power estimates computed using a rectangular window as in equation (6) or an exponentially decaying window as in equation (7)) to a power estimate (or moving average) threshold indicative of people presence over time. One way to detect people presence is to set a detection threshold a few dBs (e.g., 2-5 dBs) above a steady-state power of the power estimates. The steady-state power estimates occurs or corresponds to when adaptive filter **407** is in a steady-state, i.e., a converged state. Another way would be to compute the mean and variance over time of the power estimates in steady-state, and to set the threshold automatically as a few standard deviations (e.g., 2-5) above the mean (steady-state power). These methods for detection apply to both the case when a single subband is used, and for the case when multiple subbands are used.

At **610**, if the power estimates transition from a first level that is less than the power estimate threshold to a second level that is greater than or equal to the power estimate threshold, processor **308** issues commands to wakeup endpoint **104** if the endpoint was previously asleep.

At **615**, if the power estimates transition from a first level that is greater than or equal to the threshold to a second level that is less than the threshold, processor **308** issues commands to put endpoint **104** to sleep if the endpoint was previously awake.

In operations **610** and **615**, controller **308** may respectively issue wakeup and sleep commands to cameras **112**, display **114**, and/or portions of the controller that may be selectively awoken and put to sleep responsive to the commands. Also, timers may be used in operations **610** and **615** to ensure a certain level of hysteresis to dampen frequent switching between awake and sleep states of endpoint **104**. For example, operation **610** may require that the power estimate level remain above the threshold for a first predetermined time (e.g., on the order of several seconds, such as 3 or more seconds) measured from the time that the level reaches the threshold before issuing a command to wakeup endpoint **104**, and operation **615** may require that the power estimate level remain below the threshold for a second predetermined time (e.g., also on the order of several seconds) measured from the time the level falls below the threshold before issuing a command to put endpoint **104** to sleep.

In summary, embodiments presented herein perform the following operations: play/transmit a stationary ultrasonic

signal from a loudspeaker; convert sound picked-up by a microphone (i.e., a microphone signal) and the ultrasonic signal from the loudspeaker into the time-frequency domain; estimate an echo-free near-end signal (i.e., error signal) at the microphone with an ultrasonic frequency sub-band adaptive filter; (this is an ultrasonic echo canceling operation); compute an estimate on the power of the error signal (or a running estimate thereof); detect people presence (or a change in people presence) from the estimated power (or changes/variations) in the estimated power.

In one embodiment, detections may be used to wakeup a camera that was previously asleep, and also cause additional processing to occur, such as detection of faces and motion using video captured by the awakened camera.

In summary, in one form, a method is provided comprising: transmitting an ultrasonic signal into a spatial region; transducing ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region at a microphone into a received ultrasonic signal; transforming the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains that cover respective ultrasound frequency ranges; computing an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasonic signal and the transformed received ultrasonic signal; computing power estimates of the error signal over time; and detecting a change in people presence in the spatial region over time based on a change in the power estimates of the error signal over time.

In another form, an apparatus is provided comprising: a loudspeaker configured to transmit an ultrasonic signal into a spatial region; a microphone configured to transduce ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region into a received ultrasonic signal; a processor coupled to the loudspeaker and the microphone and configured to: transform the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains; compute an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasound signal and the transformed received ultrasonic signals; compute power estimates of the error signal over time; and detect a change in people presence in the spatial region over time based on a change in the power estimates of the error signal over time.

In yet another form, a (non-transitory) processor readable medium is provided. The medium stores instructions that, when executed by a processor, cause the processor to: cause a loudspeaker to transmit an ultrasonic signal into a spatial region; access a received ultrasonic signal representative of transduced ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region at a microphone; transform the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains that cover respective ultrasound frequency ranges; compute an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasonic signal and the transformed received ultrasonic signal; compute power estimates of the error signal over time; and detect a change in people presence in the spatial region over time based on a change in the power estimates of the error signal over time.

The above description is intended by way of example only. Various modifications and structural changes may be made therein without departing from the scope of the concepts described herein and within the scope and range of equivalents of the claims.

What is claimed is:

1. A method comprising:

transmitting an ultrasonic signal into a spatial region;

transducing ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region at a microphone into a received ultrasonic signal;

transforming the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains that cover respective ultrasound frequency ranges;

computing an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasonic signal and the transformed received ultrasonic signal;

computing power estimates of the error signal over time; and

detecting a change in people presence in the spatial region over time based on a change in the power estimates of the error signal over time.

2. The method of claim **1**, wherein the computing an error signal includes:

adaptively filtering at least one ultrasonic frequency subband of the transformed ultrasonic signal based on a set of adaptive filter coefficients adjusted responsive to the error signal to produce an estimate of the echo in the frequency subband;

differencing the estimated echo and the transformed received ultrasonic signal in at least one of the frequency subbands thereof to produce the error signal; and

feeding-back the error signal to the adaptively filtering operation.

3. The method of claim **2**, wherein:

the adaptively filtering includes adaptively filtering multiple ultrasonic frequency subbands of the transformed ultrasonic signal individually to produce a respective estimate of the echo for each frequency subband;

the differencing includes differencing each echo estimate and a corresponding one of multiple frequency subbands of the transformed received ultrasonic signal to produce an error signal for each frequency subband;

the computing power estimates includes repetitively computing a total power estimate based on the error signals across the frequency subbands; and

the detecting includes detecting a change in people presence over time based on a change in the total power estimates computed across the frequency subbands over time.

4. The method of claim **1**, wherein:

the computing power estimates includes computing a moving average of power estimates over time, wherein the moving average is based on a current power estimate of the error signal and one or more previous power estimates of the error signal; and

the detecting includes detecting a change in people presence over time based on a change in the moving average over time.

5. The method of claim **4**, wherein the detecting includes:

comparing the moving average of power estimates to a moving average power threshold indicative of a change in people presence in the spatial region; and

if the comparing indicates that the moving average of power estimates has changed from a first level below the threshold to a second level equal to or greater than the threshold, then declaring that people are present in the spatial region.

6. The method of claim 5, further comprising:
if it is declared that people are present in the spatial region, issuing one or more commands to wakeup a video conference endpoint that was previously asleep.
7. The method of claim 6, further comprising:
if it is declared that people are present in the spatial region, prior to issuing the one or more commands to wakeup the video conference endpoint, triggering the endpoint to perform face and motion detection in the spatial region; and
issuing the one or more commands to wakeup the endpoint only if the triggered face and motion detection confirms the presence of people in the spatial region.
8. The method of claim 1, wherein the detecting includes:
comparing the power estimates to a power estimate threshold indicative of a change in people presence in the spatial region; and
if the comparing indicates that the power estimates have changed from a first level below the threshold to a second level equal to or greater than the threshold, then declaring people are present in the spatial region.
9. The method of claim 8, further comprising:
if it is declared that people are present in the spatial region, issuing one or more commands to wakeup a video conference endpoint that was previously asleep.
10. The method of claim 1, further comprising:
if the detecting indicates that people are present in the spatial region, issuing a command to wakeup a video camera that was previously asleep so that the video camera is able to capture video of at least a portion of the spatial region.
11. An apparatus comprising:
a loudspeaker configured to transmit an ultrasonic signal into a spatial region;
a microphone configured to transduce ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region into a received ultrasonic signal;
a processor coupled to the loudspeaker and the microphone and configured to:
transform the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains;
compute an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasound signal and the transformed received ultrasonic signals;
compute power estimates of the error signal over time; and
detect a change in people presence in the spatial region over time based on a change in the power estimates of the error signal over time.
12. The apparatus of claim 11, wherein, to compute the error signal, the processor is configured to:
adaptively filter the transformed ultrasonic signal based on a set of adaptive filter tap weights and the error signal to produce an estimate of the echo;
difference the estimated echo and the transformed received ultrasonic signal to produce the error signal; and
feed-back the error signal to the adaptively filter operation.
13. The apparatus of claim 12, wherein:
the processor is configured to adaptively filter by adaptively filtering multiple ultrasonic frequency subbands of the transformed ultrasonic signal individually to produce a respective estimate of the echo for each frequency subband;
the processor is configured to difference by differencing each echo estimate and a corresponding one of multiple frequency subbands of the transformed received ultrasonic signal to produce an error signal for each frequency subband;
the processor is configured to compute power estimates by:
repetitively computing a total power estimate based on the error signals across the frequency subbands; and
the processor is configured to detect by detecting a change in people presence over time based on a change in the total power estimates computed across the frequency subbands over time.
14. The apparatus of claim 11, wherein:
to compute power estimates, the processor is configured to compute a moving average of power estimates over time, wherein the moving average is based on a current power estimate of the error signal and one or more previous power estimates of the error signal; and
to detect, the processor is configured to detect a change in people presence over time based on a change in the moving average over time.
15. The apparatus of claim 11, wherein the processor is configured to detect by:
comparing the power estimates to a power estimate threshold indicative of a change of people presence in the spatial region;
if the comparing indicates that the power estimates have changed from a first level below the threshold to a second level equal to or greater than the threshold, then declaring people are present in the spatial region.
16. The apparatus of claim 11, further comprising a video camera coupled to the processor, wherein the processor is further configured to:
if the detect operation indicates people are present in the spatial region, issue a wakeup command to the video camera to wakeup if the video camera was previously asleep so that the video camera is able to capture video of at least a portion of the spatial region.
17. A non-transitory processor readable medium storing instructions that, when executed by a processor, cause the processor to:
cause a loudspeaker to transmit an ultrasonic signal into a spatial region;
access a received ultrasonic signal representative of transduced ultrasonic sound, including an echo of the transmitted ultrasonic signal, received from the spatial region at a microphone;
transform the ultrasonic signal and the received ultrasonic signal into respective time-frequency domains that cover respective ultrasound frequency ranges;
compute an error signal, representative of an estimate of an echo-free received ultrasonic signal, based on the transformed ultrasonic signal and the transformed received ultrasonic signal;
compute power estimates of the error signal over time; and
detect a change in people presence in the spatial region over time based on a change in the power estimates of the error signal over time.
18. The processor readable medium of claim 17, wherein the instructions to cause the processor to compute the error signal include instructions to cause the processor to:
adaptively filter at least one ultrasonic frequency subband of the transformed ultrasonic signal based on a set of adaptive filter coefficients adjusted responsive to the error signal to produce an estimate of the echo in the frequency subband;
difference the estimated echo and the transformed received ultrasonic signal in at least one of the frequency subbands thereof to produce the error signal; and

feed-back the error signal to the adaptively filtering operation.

19. The processor readable medium of claim **17**, wherein:

the instructions to cause the processor to compute power estimates include instructions to cause the processor to compute a moving average of power estimates over time, wherein the moving average is based on a current power estimate of the error signal and one or more previous power estimates of the error signal; and

the instructions to cause the processor to detect include instructions to cause the processor to detect a change in people presence over time based on a change in the moving average over time.

20. The processor readable medium of claim **19**, wherein the instructions to cause the processor to detect include instructions to cause the processor to:

compare the moving average of power estimates to a moving average threshold indicative of people presence in the spatial region; and

if the comparing indicates that the moving average has changed from a first level below the threshold to a second level equal to or greater than the threshold, then declare people are present in the spatial region.

* * * * *